HYDROGEOLOGY OF THE SIR SAMUEL 1:250 000 SHEET

HM 11
2004

HYDROGEOLOGICAL MAP EXPLANATORY NOTES SERIES

Department of Environment

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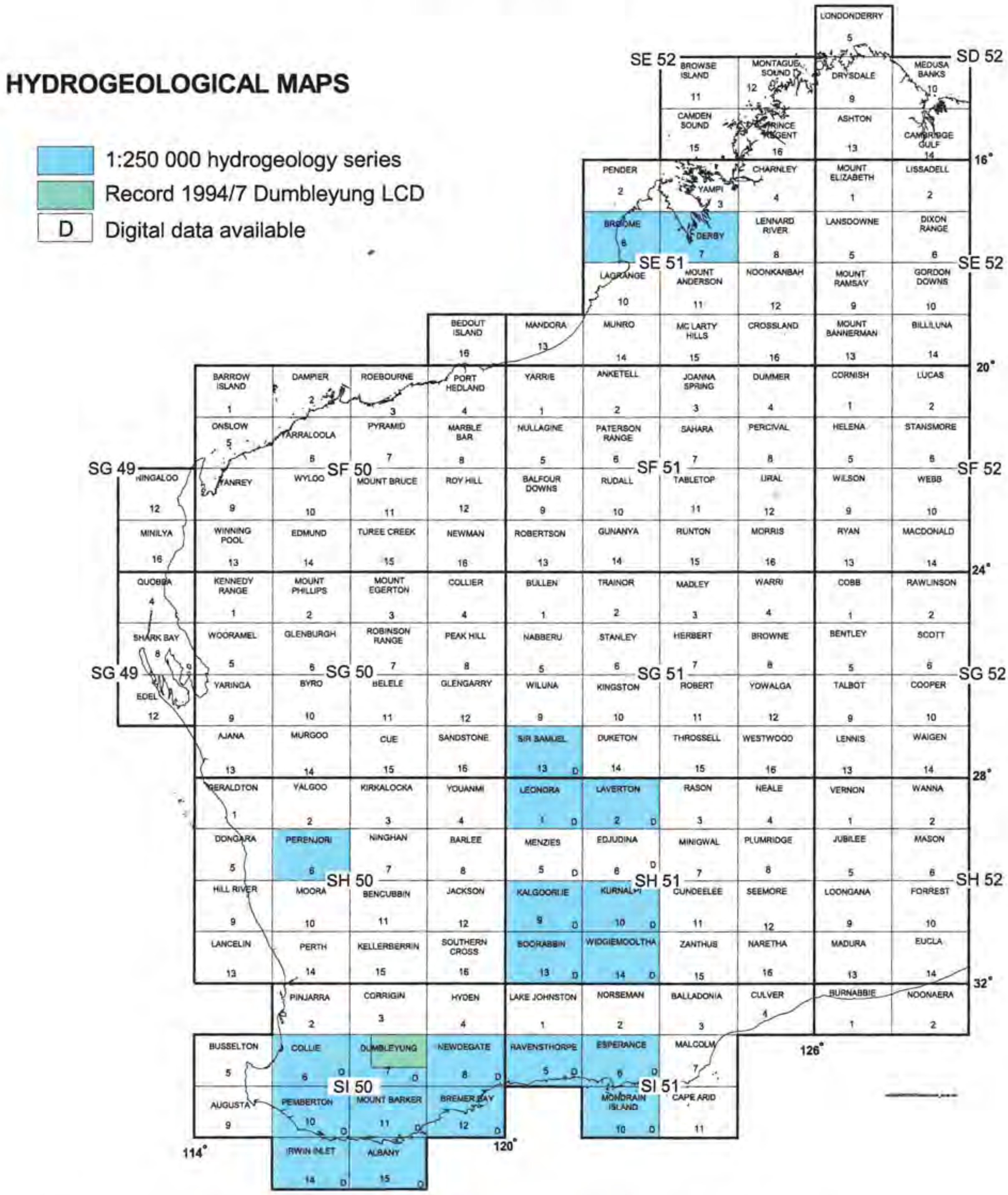

Cover Photograph: Granite outcrop near Depot Springs in the southeast corner of SIR SAMUEL.

DEPARTMENT OF CONSERVATION
AND LAND MANAGEMENT
WESTERN AUSTRALIA

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by
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HYDROGEOLOGY OF THE SIR SAMUEL 1:250 000 SHEET

BY

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Abstract

The SIR SAMUEL 1:250 000 hydrogeological sheet covers a part of the Yilgarn Craton that is characterised by north-northwesterly trending belts of Archaean greenstones intruded by granitoid rocks. Cainozoic surficial deposits form an extensive cover over the Precambrian bedrock and conceal Tertiary sedimentary rocks preserved in palaeochannels.

Fractured-rock aquifers occupy the greater part of the SIR SAMUEL area, but they generally contain only minor groundwater supplies, and these are difficult to locate. The palaeochannel sand and calcrete are considered to be the most prospective aquifers on SIR SAMUEL. There are significant groundwater resources within the alluvium that are best utilised via downward leakage into either underlying palaeochannel sands or permeable structures in the basement.

Most of the groundwater on SIR SAMUEL is fresh to brackish and is extensively used by the pastoral industry. Important brackish groundwater resources have also been identified in the palaeochannel tributaries throughout the sheet area. Saline to hypersaline groundwater occurs along the palaeodrainages and is currently used only for mining purposes.

The groundwater resources in the palaeochannels are being developed for use in ore processing; however, the fresh to brackish groundwater in the tributaries has potential for potable water supply or horticultural development. A number of borefields have also been established in the alluvium, calcrete and fractured-rock aquifers throughout SIR SAMUEL to provide water to the town of Leinster and the mining industry.

Keywords: hydrogeological maps, groundwater, aquifers, palaeochannels, Northern Goldfields.

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1 Introduction

1.1 Location

The SIR SAMUEL[1] hydrogeological sheet (SG 51-13 of the International Series), which is bounded by latitudes 27°00' and 28°00' S and longitudes 120°00' and 121°30' E, lies within the northern part of the Eastern Goldfields Province of Western Australia. The map sheet takes its name from the abandoned mining town of Sir Samuel, located towards the centre of the sheet area.

Mining is the major activity of the region with most of the population concentrated in Leinster. The remainder of the sheet is sparsely populated, except for individual pastoral homesteads and scattered mining operations at Mount Keith, Mount McClure, Bronzewing and Darlot.

The sheet area is reached via the Goldfields Highway, linking Wiluna in the north to Leonora and Kalgoorlie in the south and is sealed as far north as Mount Keith. Good-quality, shire-maintained unsealed roads connect the major mining centres and pastoral properties. In addition, there is a network of fence-line tracks, suitable only for four-wheel drive vehicles, which provide access to more remote locations.

Pastoral properties carrying sheep occupy most of the sheet area, with mineral exploration and mining being restricted to the greenstone areas.

1.2 Climate

The climate is semi-arid to arid with hot, dry summers and cool to mild winters. January is the hottest month with an average maximum temperature of 38°C and an average minimum of 19°C at Yeelirrie. July is the coolest month with an average maximum temperature of 23°C and an average minimum of 4°C. Frost occasionally occurs during the winter months.

The average annual rainfall is 233 mm at Yeelirrie, but this is unreliable and the area is often subjected to both drought and localised short-term floods. The rainfall is evenly distributed between the summer and winter months, although heaviest in summer, when it is associated with thunderstorm activity or rain-bearing depressions formed from tropical cyclones.

Average annual potential evaporation increases from about 3600 mm in the south to 3900 mm in the northeast. Evaporation is greatest during the summer months of January and February and lowest during the winter months of June and July.

1.3 Physiography

Most of the area is gently undulating and of subdued relief, with elevations between 440 and 540 m AHD (Australian Height Datum). Throughout SIR SAMUEL numerous granite monadnocks protrude slightly above the land surface, and greenstones and banded iron-formation form prominent hills and ridges such as Mount Keith (594 m AHD), Mount Mann (554 m AHD) and Mount White (547 m AHD). The sheet area is characterised by broad alluviated valleys and playa lakes, which mark the courses of palaeorivers that ceased to flow when the climate became arid during the Tertiary. On SIR SAMUEL, these palaeorivers form two distinct drainage systems, or palaeodrainages (Fig. 1).

[1] Sheet names are printed in capitals to distinguish them from identical place names

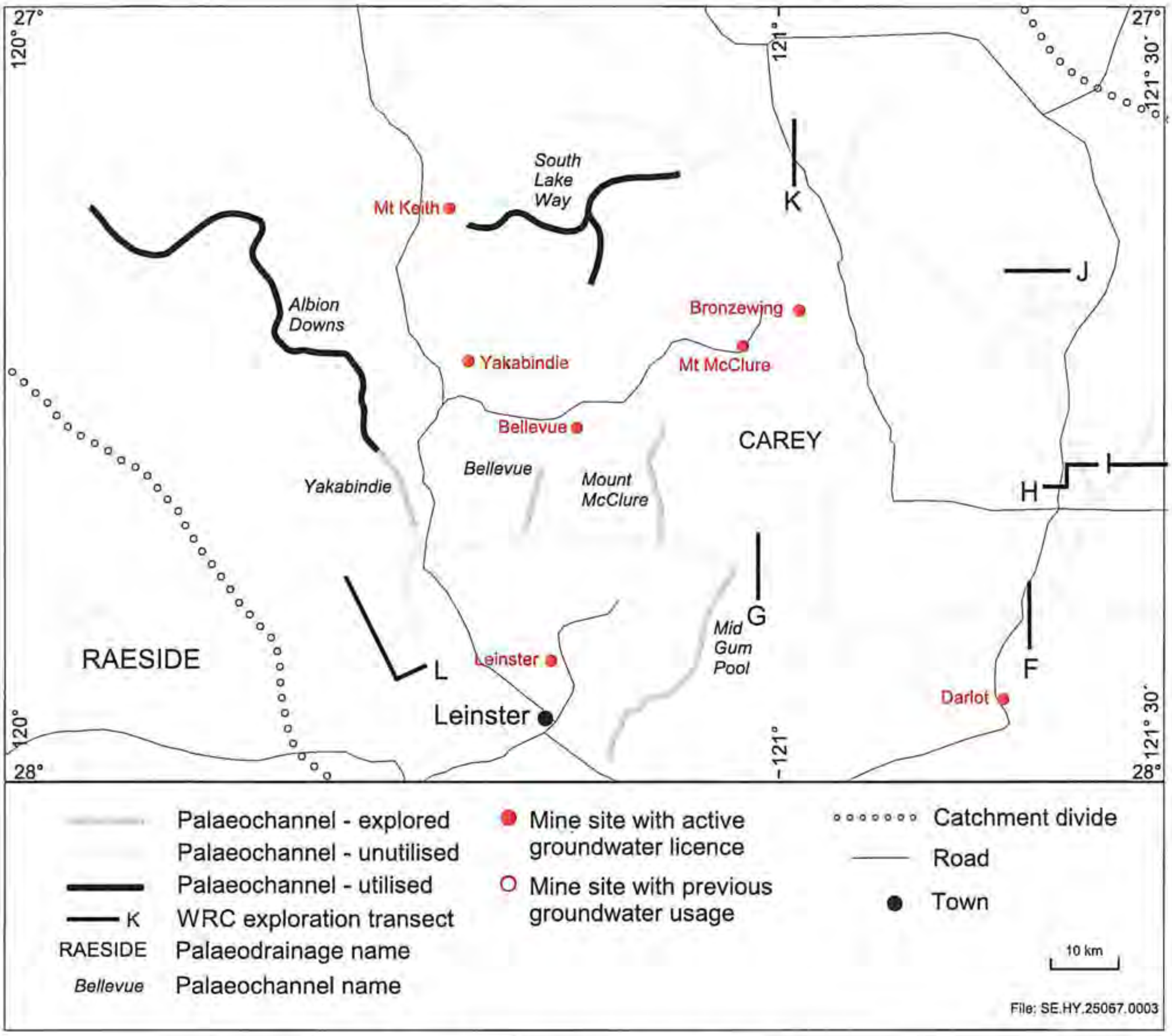

Figure 1. Location and palaeodrainages.

A major surface-water divide crossing SIR SAMUEL separates the Carey and Raeside Palaeodrainages (Beard, 1973; Bunting *et al*, 1974; van de Graaff *et al.*, 1977). These palaeodrainages once carried water east to the Eucla Basin but are now occupied by chains of playa lakes. The headwaters for both the Carey and Raeside Palaeodrainages are located to the west and north of the sheet area.

There are no permanent rivers; intermittent streamflow occurs only after major rainfall and the water runs into playa lakes. Runoff from bedrock outcrops may collect in gnamma holes or rock holes, and soaks and water holes commonly occur next to rocky outcrops.

1.4 Vegetation

The vegetation is quite diversified throughout SIR SAMUEL and is controlled by soil type (Beard, 1981). Most of the area comprises low woodland dominated by mulga and mixed eucalypt scrub. Mulga and mallee shrubland thrive on elevated rocky features such as greenstone ridges. In the granite and sandplain areas, spinifex hummock grasslands with scattered mulga and eucalypt overstorey are prominent. The drainage lines are commonly occupied by thick woodland, with salt-tolerant halophytes, such as samphire and saltbush, surrounding the playa lakes.

Large areas of mulga and mallee trees around mining centres were cleared for firewood and timber during the initial mining activities, although this vegetation is regenerating. In the pastoral areas, overstocking and feral animals such as goats and rabbits have caused local erosion and land degradation.

1.5 Previous investigations

Early contributions of the geology of SIR SAMUEL include descriptions of gold-mining areas at Sir Samuel, Darlot and Mount Keith. The first edition of the SIR SAMUEL geological sheet was compiled in 1974 (Bunting and Williams, 1979) and included a bibliography of previous publications. The Bureau of Mineral Resources (BMR, now Geoscience Australia) published the results of an aeromagnetic and radiometric survey (Shelley and Waller, 1967). Griffin (1990) outlined the regional geology of the Eastern Goldfields Province, but to date, there has been no complete synthesis of the geology in the north Eastern Goldfields region. The entire SIR SAMUEL sheet was remapped at 1:100 000 scale between 1994 and 1998 by the Geological Survey of Western Australia (Liu *et al.*, 1996; Wyche and Griffin, 1996; Wyche and Westaway, 1996) and the Australian Geological Survey Organisation (now Geoscience Australia) (Champion and Stewart, 1995; Lyons, 1996; Jagodzinski *et al.*, 1997). A review of mineral occurrence and exploration potential in the north Eastern Goldfields has been published by Ferguson (1998).

The first description of the regional hydrogeology and the availability of groundwater was by Morgan (1966), who undertook bore siting for various pastoral leases. The calcrete aquifers on SIR SAMUEL were evaluated by Sanders (1969) and Sanders and Harley (1971) to determine their potential for irrigation and mine water supplies. Forbes (1978) made an assessment of the groundwater resources of the Eastern Goldfields in response to concerns about the availability of groundwater for mining supplies. This was subsequently revised by Bestow (1992), who provided regional estimates of the renewable and stored groundwater resources for each 1:250 000 sheet area. Allen (1996) provided a description of the hydrogeology and groundwater availability, but did not assess the groundwater resources. The Water and Rivers Commission carried out a major study of the groundwater resources in the Northern Goldfields between 1996 and 1999 (Johnson et al., 1999). This study included a drilling program and geophysical survey (Johnson *et al.*, 1998; Tesla-10, 1997). The hydrogeology of the adjacent LAVERTON and LEONORA 1:250 000 sheets were compiled in 1999 (Johnson, 1999a,b).

Considerable groundwater exploration and development has been carried out on SIR SAMUEL for the mining industry over the past thirty years by hydrogeological consultants. Geotechnics (1972) conducted a large groundwater exploration program to evaluate the groundwater resources of the Agnew area for WMC and the Public Works Department (PWD). This study focused on the Depot Springs area, southeast corner of SIR SAMUEL, and employed resistivity surveys prior to drilling (Cowan and Omnes, 1975).

Borefields have been established for mining developments throughout the region, with a large amount of work having been carried out for the nickel operation at Mount Keith, and gold operations at Bronzewing, Darlot and Mount McClure. Recent groundwater exploration has concentrated on locating water supplies in palaeodrainages. Groundwater in the fractured-rock environment near Leinster has been described by Whincup and Domahidy (1982a,b).

1.6 Map compilation

The hydrogeological map of SIR SAMUEL depicts aquifer distribution, potentiometric levels in metres AHD (for the palaeochannel aquifers), groundwater salinity (isohalines), groundwater point-data distribution and cadastral data. Data used in the compilation of the map include: cadastral data from Department of Land Administration; geology from GSWA (Ferguson et al., 1998); pastoral bore data from the Water and Rivers Commission groundwater database (AQWABase); mining bore data from groundwater consultant and mining company reports (held by the Water and Rivers Commission); WAMEX mineral exploration drilling and MINEDEX mining operation locality data from the Department of Industry and Resources.

The SIR SAMUEL hydrogeological map is, at the 1:250 000 scale, a generalisation of the data which have been entered into a digital database and stored as graphical layers of information. Interpretation of the data was conducted at 1:250 000 scale, which should be considered when working at larger scales. The hydrogeological boundaries, potentiometric contours and isohalines are interpretative and must be taken as approximate. The most accurate interpretation is associated with mine production borefields, whilst areas with limited pastoral bore distribution have only reliable salinity information.

2 Geology

2.1 Regional setting

The SIR SAMUEL sheet lies within the Eastern Goldfields Province of the Yilgarn Craton (Griffin, 1990; Myers, 1997). It is characterised by linear, north-northwesterly trending greenstone belts of Archaean supracrustal rocks comprising metamorphosed volcanic and sedimentary rocks, with intervening areas of granitoid rocks. Proterozoic dykes cut both the greenstone and granitoid rocks.

Cainozoic surficial deposits form an extensive cover over the Precambrian rocks, and include Tertiary sedimentary rocks preserved in palaeochannels located in palaeodrainages that once carried water eastward to the Eucla Basin.

2.2 Archaean and Proterozoic

There are three main greenstone belts, Agnew–Wiluna, Yandal and Duketon, on SIR SAMUEL. These belts contain metamorphosed and deformed sequences of mafic (*Ab*) and ultramafic (*Au*) volcanic rocks; felsic volcanic and volcaniclastic rocks (*Af*); sedimentary rocks (*As*); and minor chert and banded iron-formation (*Ac*). A variety of granitoid rocks (*Ag*), generally foliated, occupy about 60% of SIR SAMUEL. The Archaean bedrock is poorly exposed on SIR SAMUEL owing to widespread surficial cover and deep weathering.

Granitoid emplacement has extensively deformed the greenstone belts resulting in complex geological structures (Myers, 1997). The contacts are characterised by strong deformation, local high-grade metamorphism, and interleaving of granitoid and greenstone rocks. As a result of their deformation, the greenstones are highly sheared and fractured. In contrast, the granitoids are generally massive except for jointing and local fracturing developed adjacent to the greenstone contacts.

Proterozoic mafic and ultramafic dykes (*Pd*) intrude the granite–greenstone terrane throughout the SIR SAMUEL area. The dykes are widespread, less than 200 m across, with easterly and northeasterly trends, and can be traced as aeromagnetic lineaments.

Most rock types have been lateritised and deeply weathered over much of the area, resulting in deep sections that are completely weathered to clay, or partially weathered with the original texture preserved. The weathering profile is commonly 30–40 m thick, but reaches about 120 m at the Darlot Gold mine (K.H. Morgan and Associates, 1994) and 90 m in exploratory holes at the Cams project (K.H. Morgan and Associates, 1997). The weathered granitoid profile is principally characterised by large thicknesses of kaolin, which may extend to a depth of 50 m. In places, a quartz-rich grit comprising partially decomposed basement directly overlies the fresh granitoid rock and is often misinterpreted as palaeochannel sand.

2.3 Cainozoic

2.3.1 Tertiary sedimentary rocks

Tertiary sedimentary rocks deposited in valleys cut by Cretaceous to early Tertiary rivers form palaeochannels that are now concealed by Cainozoic sediments. On the map, these sediments are shown in blue with solid lines where proven by drilling and geophysics, and dashed lines where they are inferred to be present. Their distribution is interpreted between drillholes.

Sediments in the Carey and Raeside Palaeodrainages on SIR SAMUEL have been described in Johnson *et al.* (1999), and are similar to those in the Roe Palaeodrainage (Kern and Commander, 1993). They typically comprise basal fluvial sand (*Tw*) overlain by lacustrine clay (T*p*). The palaeochannel sand, which reaches a thickness of 40 m beneath Transect K, consists of unconsolidated quartz sand with minor silt, clay and lignite. The unit is Eocene in age and is an equivalent of the Wollubar Sandstone (Kern and Commander, 1993). The palaeochannel clay is a multicoloured, plastic clay with minor sand and pisolitic beds, and reaches a thickness of 85 m beneath Transect I. The unit becomes more silty and sandy in the upper parts of the palaeochannels.

The palaeochannels and their tributaries, delineated by drilling in the Carey Palaeodrainage, range in width from 200 m in Transect I and J to over 1000 m in Transect G on SIR SAMUEL, and may be 125 m deep where bedrock is deeply incised.

Sediments in the Raeside Palaeodrainage are not explored on SIR SAMUEL; however, further downstream they are similar to those in the Carey Palaeodrainage (Johnson *et al.*, 1999).

2.3.2 Surficial deposits

A variety of Cainozoic surficial deposits (*Ql*, *Cza* and *Czk*) are encountered on SIR SAMUEL, where they form a veneer over the Archaean and Tertiary rocks. Cainozoic surficial deposits in elevated areas are generally unsaturated and are not mapped. Only those units that are likely to contain groundwater are shown on the map.

High-level deposits of laterite, eluvium, and sandplain are widespread. The laterite occurs as plateaus of massive, ferruginous duricrust, bounded in part by breakaways, and as pisolitic soil in lower areas. The eluvium consists of quartzofeldspathic sand derived by weathering and erosion of granitoid rocks with scattered, small pebbles of granitoid rocks. Sandplain deposits, which are partly eolian in origin, consist of low dunes of red-brown sand forming extensive, gently undulating areas on SIR SAMUEL.

Alluvial and colluvial deposits (*Cza*) are widespread throughout SIR SAMUEL. The unit has a variable thickness of up to 50 m in the Albion Downs borefield (Berry, 1994). This variation in thickness is largely dependent on position in the drainage system, with the thickest sequences often coinciding with the axes of the Tertiary palaeochannels. The alluvium occurs as coalesced alluvial fans and broad sheetwash areas consisting of unconsolidated sand, silt and clay. In places, the alluvium has been cemented by silica, iron oxide or carbonate to form a hardpan, locally termed the 'Wiluna Hardpan' (Bettenay and Churchward, 1974). Thin deposits of colluvium, less than 20 m at Transect I, form along the flanks of greenstone ridges and comprise subrounded, iron-stained gravels and angular rock fragments within a clay matrix (Johnson *et al.*, 1999).

Bodies of calcrete (*Czk*) exist at the margins of present-day salt lakes, and locally in some of the main tributaries in the palaeodrainages (Sanders, 1974). The calcrete rarely exceeds 10 m in thickness, except in the Depot Springs Palaeochannel, where up to 40 m of calcretised alluvium has been identified (Geotechnics, 1972). Karstic features, including sinkholes and gilgai structures, are often developed due to the susceptibility of the calcrete to chemical dissolution via percolating surface water and groundwater movement.

Deposits associated with playa lakes (*Ql*) consist of saline and gypsiferous clay and silt that may be up to 7 m thick in Lake Darlot (Glassford, 1987). They typically overlie highly weathered Archaean rocks, or alluvium within the trunk palaeodrainages. The lake margins consist of stabilised dunes of unconsolidated sand, silt and gypsum derived from the desiccated surface of the playa lakes.

3 Hydrogeology

3.1 Groundwater occurrence

The SIR SAMUEL area is underlain by weathered and fractured Archaean bedrock, which forms the northern portion of the Yilgarn Goldfields fractured-rock groundwater province. The bedrock is overlain locally by palaeochannel deposits, and by widespread alluvium, colluvium, calcrete and lake deposits.

The fractured bedrock is characterised by secondary permeability resulting from chemical weathering of tectonic and decompression fracture systems. Fractured-rock aquifers are more commonly developed in mafic, ultramafic and granitoid rocks than in sedimentary or felsic volcanic and volcaniclastic rocks. The maximum depth to which open fractures penetrate is 350 m in the Perseverance underground operations associated with the Perseverance and 60A Faults (Whincup and Domahidy, 1982b). Groundwater can be inferred to occur to a similar depth along major faults and shear zones. Vuggy weathering profiles developed in ultramafic volcanic rocks also constitute an important local aquifer.

Minor mafic and ultramafic dykes occur in the western half of SIR SAMUEL. They are undeformed, generally appear to lack open fractures, and are possibly hydraulic barriers to groundwater movement.

The palaeochannel sand is highly permeable and contains significant supplies of groundwater, which is fresh to brackish in the tributaries and saline to hypersaline in the main trunk drainages. The sand, however, has limited groundwater storage with most groundwater abstracted being the result of induced leakage from overlying sediments and surrounding fractured-rock aquifers.

Groundwater is contained within the primary porosity of the alluvium, whereas calcrete exhibits increased secondary permeability through chemical dissolution. Although, the alluvium aquifer has low permeability owing to its clayey nature, the calcrete can often provide large local supplies of fresh to brackish groundwater from solution cavities.

Direction of groundwater flow and variation in salinity are closely related to topography, whereas bore yields depend largely on rock type.

Groundwater occurrence on SIR SAMUEL is illustrated in Figure 2. Groundwater recharge is difficult to estimate as it constitutes a very small proportion of rainfall, most of which is either directly evaporated or utilised by the native vegetation, with a small component of runoff into claypans and playa lakes. Direct recharge principally takes place around bedrock outcrops, in the sandplains, and sinkholes within the calcrete. Most recharge is likely to occur during heavy rainfall, when it is augmented by recharge from surface runoff and local flooding.

There is a regional watertable on SIR SAMUEL. Depth to groundwater is dependent on topography ranging from less than 1 m in playa-lake environments to more than 40 m in elevated areas. The regional watertable may be absent in high areas where the weathered and fractured zone is unsaturated or where fractures are poorly developed.

Groundwater flow is towards the major palaeodrainages and modern playa lakes where the watertable is close to the surface. Hydraulic gradients along the palaeodrainages are generally very low, with steeper gradients in the upper reaches of the catchments, and where the palaeochannel crosses greenstone ridges, such as south of Transect H. Groundwater discharge is mainly by evaporation from playa lakes with a relatively small amount by throughflow within the palaeochannels.

The units on the accompanying map represent distinct hydrogeological units with lithological associations similar to those used on geological maps.

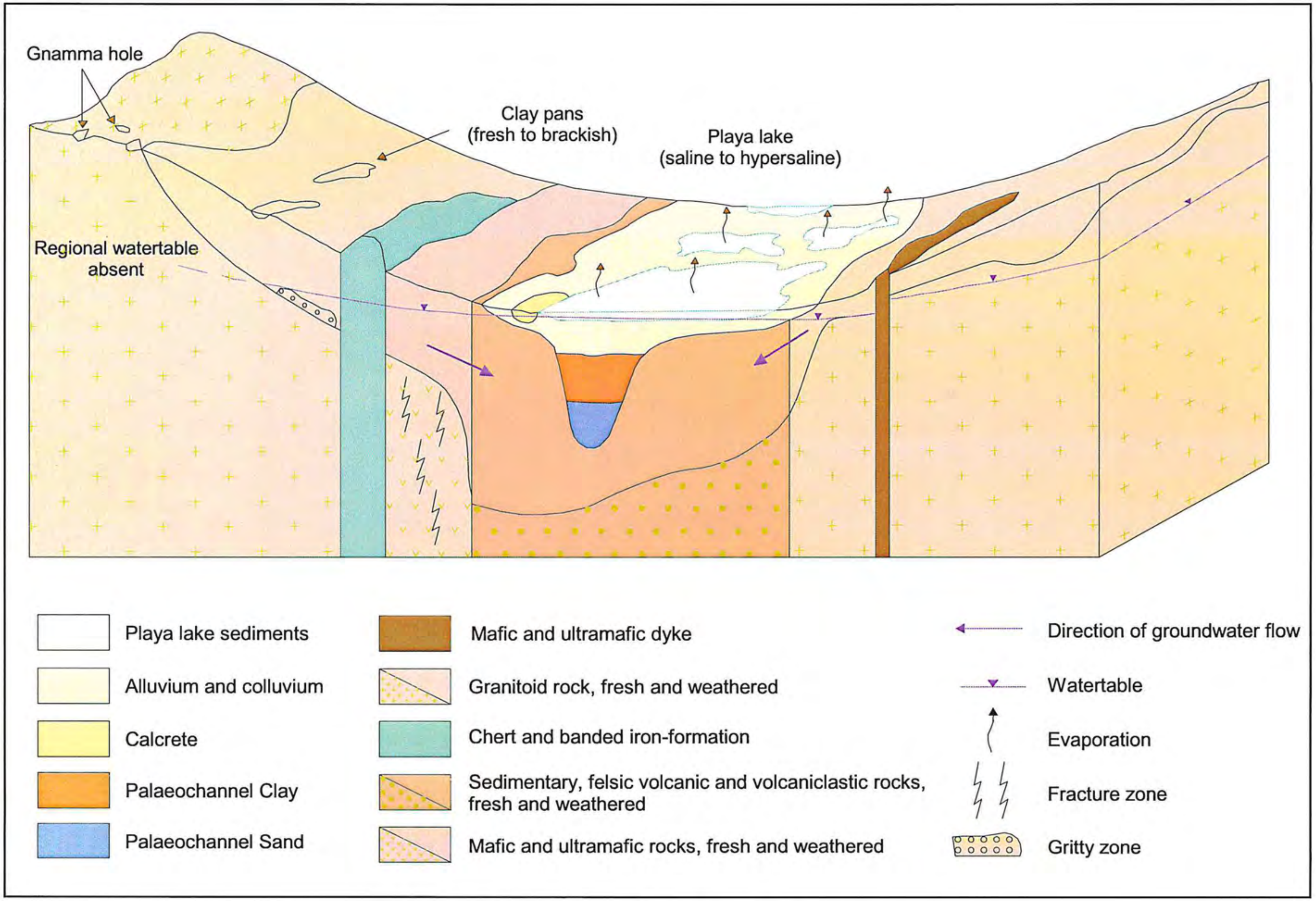

Figure 2. Schematic section showing groundwater occurrence.

3.2 Aquifers

3.2.1 Surficial deposits (*Ql*, *Cza* and *Czk*)

Lacustrine sediments (*Ql*) are intermittently saturated as the lakes are usually dry for most of the year and are replenished only after heavy rainfall. The regional watertable is close to the surface in playa-lake environments. The sediments are generally fine grained to clayey, with bore and well yields likely to be low. They are not utilised as aquifers on SIR SAMUEL. Playa lakes commonly have marginal gypsiferous sand and clay deposits that are not mapped but may contain a perched watertable.

Alluvial and colluvial deposits (*Cza*) occur as channel fill associated with palaeodrainages, and comprises unconsolidated silty sand and minor gravel. Minor deposits of colluvium interfinger the alluvium, and have been mapped together owing to their possessing similar aquifer properties.

The poorly sorted sediments form an unconfined aquifer with a shallow watertable and an average saturated thickness of between 5 and 15 m. The permeability of the alluvium is generally low, with its silty nature limiting hydraulic conductivity to less than 2.5 m/day in the Albion Downs borefield (Berry, 1997). The hydraulic conductivity can, however, increase significantly in permeable sand and gravel horizons, and calcretised sections. In addition, the alluvial aquifer is often partly indurated by siliceous and ferruginous cement, possibly representing previous watertable positions, which has secondary porosity and high permeability developed in bands.

Bore yields from the alluvium are variable and range between 50 and 900 m^3/day reflecting the variability in hydraulic conductivity. Short-term yields up to 1200 m^3/day have been recorded during pumping tests on SIR SAMUEL. The largest yields are from unconsolidated, clayey, rounded basaltic gravels that form colluvial deposits at the base of greenstone ridges, such as those intersected on Transect H (Johnson *et al.*, 1998).

The aquifer is directly utilised on SIR SAMUEL in the Bellevue, Bronzewing and Yakabindie borefields. However, owing to the low permeability of the alluvium, most groundwater obtained is through leakage into underlying palaeochannel and fractured-rock aquifers, such as in Albion Downs and 11-Mile Well borefields.

Calcrete (*Czk*) is an important local aquifer in the Northern Goldfields capable of providing large supplies of brackish groundwater. The aquifer occurs low in the drainage systems where the watertable is generally shallow (<5 m below ground level) and saturated thickness is mostly between 5 and 10 m. Bore yields are highly variable depending on the nature and extent of karstic development. Bore yields at Depot Springs (Geotechnics, 1972) ranged from less than 100 m^3/day in massive calcrete to 4400 m^3/day in highly karstic calcrete.

The calcrete aquifer is utilised on SIR SAMUEL only in the Darlot borefield, although numerous calcrete bodies have been extensively explored for mine-process water throughout the sheet area, primarily near Yeelirrie and Depot Springs. The pastoral industry also utilises groundwater from the calcrete via shallow bores and wells equipped with windmill-powered pumps that yield up to 20 m^3/day.

3.2.2 Tertiary sedimentary rocks (*Tp* and *Tw*)

The palaeochannel sand is the major aquifer in the Northern Goldfields region. The sand aquifer is confined throughout SIR SAMUEL by relatively impermeable clay, although the confining clay layers in the tributaries are often silty and contain multiple sand horizons.

The standing water levels in observation bores range from about 2 m below ground surface in exploratory bores in Transect F (Johnson *et al.*, 1998) to about 20 m in the South Lake Way borefield (Haselgrove *et al.*, 1998). Groundwater flow in the sand aquifer is generally eastward, in the direction of the original drainage. In the Carey Palaeodrainage, the potentiometric surface falls from about 510 m AHD in the upper reaches of the South Lake Way borefield to about 335 m AHD where the Carey Palaeochannel meets the Way Palaeochannel in the southeast of SIR SAMUEL. Owing to groundwater abstraction, the current potentiometric head is about 2–3 m lower in the sections of the Carey Palaeochannel, such as in the Albion Downs borefield (Haselgrove *et al.*, 1998).

The hydraulic gradient in the Carey Palaeodrainage steepens to the south of Transect H (0.8 m/km), where the palaeochannel narrows and passes through the more resistant belts of mafic rocks. In the vicinity of salt lakes, the hydraulic gradient is very low (about 0.2 m/km) suggesting groundwater discharge through evaporation at lake surfaces.

Bore yields from the sand aquifer are variable ranging between 200 and 1200 m^3/day (Table 1). Short-term yields in excess of 2000 m^3/day have been recorded during pumping tests on SIR SAMUEL with larger yields dependent on grain size, thickness and extent of sand. Monitoring results from major borefields in the Carey Palaeodrainage have indicated that confined conditions still apply after several years of pumping and that drawdowns have been lower than predicted from short-term pumping tests. This suggests that there is significant groundwater inflow from tributaries, weathered and fractured bedrock, and by leakage from the overlying sediments.

There are five major borefields on SIR SAMUEL that directly utilise the palaeochannel sand aquifer in the Carey and Way Palaeochannels. These include the Albion Downs, South Lake Way and Lake Way borefields for WMC's Mount Keith operations, Mid Gum Pool and Allans Pool at Leinster Nickel, and several bores in the Mount McClure borefield. There has also been exploration in the Carey Palaeochannel, downstream of Albion Downs borefield, for the proposed Yakabindie project, as well as in the Grey Mare Palaeochannel as part of Murrin Murrin processing water requirements.

The Raeside Palaeochannel is not currently utilised on SIR SAMUEL; however, it is believed to contain sediments similar those in the Carey and Way Palaeochannels (Johnson *et al.*, 1999).

3.2.3 Granitoid rocks (*Ag*)

Granitoid rocks, which occupy about 60% of SIR SAMUEL, consist of even-grained to porphyritic granite, monzogranite and granodiorite that are generally foliated and metamorphosed. They are poorly exposed with extensive areas of granitoid rocks overlain by residual sandplains and colluvium. In outcrop, granitoid rocks appear to be massive with only minor foliations and joints, although widely spaced jointing is evident on air photos.

In places, the granitoid rocks are deeply weathered to more than 100 m, with the thicker profiles occurring along shear zones or beneath the palaeodrainages. Bore yields of up to 100 m^3/day are obtainable from both the quartz-rich grit at the base of the weathered profile, and fractures in the uppermost 10 to 20 m of fresh rock. Larger supplies, up to 1500 m^3/day, are available from lineaments, probably faults or shear zones, within the granitoids and at the contact with greenstone rocks.

Pegmatite dykes and quartz veins (not mapped) are a minor, but widespread, component of the granitoid rocks. These tend to be well fractured and may form small but locally important aquifers. They are also present in the greenstone belts. Proterozoic mafic dykes (*Pd*) commonly intrude the Archaean granitoid rocks and weather to massive, impermeable clay.

The granitoids are poorly explored throughout SIR SAMUEL owing to their low mineral prospectivity and poor groundwater prospects due to their homogeneity and sparse fracturing (Johnson *et al.*, 1999). The 11-Mile Well borefield, which provides large supplies of potable groundwater to Leinster, is the only borefield established in weathered and fractured granite (Whincup and Domahidy, 1982a). This borefield is located along two major structural lineaments resulting from displacement along the Perseverance Fault.

The aquifer is locally weathered down to 80 m, with the largest yields from the transitional zone where the fracturing has been enhanced by secondary weathering, and at structural contacts with adjacent ultramafic rocks. The long-term sustainability of the borefield is dependent on accessing the stored groundwater resources in the overlying alluvium via downward leakage into the more permeable granite aquifer (Groundwater Resources Consultants, 1989).

3.2.4 Chert and banded iron-formation (*Ac*)

Chert and banded iron-formation are common only in the eastern half of SIR SAMUEL, where they are associated with mafic and ultramafic volcanic rocks and form prominent narrow ridges. Chert and banded iron-formation have well-developed joint systems as a result of brittle deformation, and are not deeply weathered. They have not been explored on SIR SAMUEL, but may have local potential as fractured aquifers.

3.2.5 Sedimentary, felsic volcanic and volcaniclastic rocks (*As* and *Af*)

A complex succession of metamorphosed sedimentary rocks, and felsic volcanic and volcaniclastic rocks is widespread in the greenstone belts. The felsic extrusive rocks are well represented in the Yandal Belt and Mount Keith area and include dacite, schists and felsic tuffs that tend to be foliated, relatively unjointed and have fine-grained weathering products. The sedimentary rocks that occur in the southern half of the Yandal and Agnew–Wiluna Belts comprise quartz-rich siltstones, sandstones and conglomerates that are fine grained, strongly deformed and deeply weathered.

Sedimentary, felsic volcanic and volcaniclastic rocks are likely to constitute poor sources of groundwater owing to their clay-rich weathering products. These aquifers are largely unutilised on SIR SAMUEL, except in the Village borefield, where one production bore is established along the lithological contact between felsic volcanic and ultramafic rocks.

3.2.6 Mafic and ultramafic rocks (*Ab* and *Au*)

Mafic and ultramafic rocks are the dominant rock types in the greenstone belts. The mafic rocks comprise extrusive basalt, amphibolite and high-Mg basalt that tend to be characterised by columnar jointing. However, in outcrop the mafic rocks are commonly highly weathered and the joints are filled with clay. Ultramafic rocks are concentrated mainly in the Agnew–Wiluna Belt and include dunite, talc schists and talc-carbonate rocks that are typically thin, deeply weathered and poorly exposed. In places, a porous siliceous caprock has developed by weathering of the underlying ultramafic (dunite) rock (Whincup and Domahidy, 1982a).

The watertable is deep in the upper reaches of the catchments, as much as 32 m in the Caprock borefield. Groundwater levels in mine shafts sunk in mafic and ultramafic rocks can also be deep where mines are located in elevated areas.

Although the mafic rocks are poorly explored on SIR SAMUEL, it is known that they may form local fractured aquifers. In contrast, the major fractured-rock borefields are typically developed in ultramafic rocks associated with either the caprock aquifer or structural contacts adjacent to granitoids. The vuggy siliceous caprock aquifer is capable of bore yields up to 1500 m^3/day in the Caprock borefield. However, this aquifer has limited areal extent and is largely restricted to the Agnew–Wiluna Belt between Leinster and Mount Keith. In the Perseverance Fault borefield, good supplies of groundwater are obtained from the Perseverance Fault and associated fracturing within the contact between ultramafic and granitoid rocks. The Village borefield provides moderate supplies of potable groundwater for WMC's Mount Keith operations from production bores established within structural contacts between mafic, ultramafic and granitoid rocks.

4 Groundwater quality

4.1 Salinity

4.1.1 Regional variation

The distribution of groundwater salinity on SIR SAMUEL in all aquifers is related to topography. Groundwater tends to increase in salinity towards and along the drainage lines, particularly the palaeodrainages, with the lowest salinity groundwater beneath catchment divides.

The mapped salinity pattern, displayed as a side panel on the hydrogeological map, is based on pastoral bore data held in AQWABase and represents the salinity of groundwater at the watertable. It is important to note that this data set is non-synoptic and does not include unrecorded bores that may have been abandoned after drilling because of high salinity or low yields.

Groundwater salinity on SIR SAMUEL is highly variable, ranging from less than 1000 mg/L total dissolved solids (TDS) in fractured-rock aquifers along catchment divides, to more than 200 000 mg/L TDS in brines in palaeochannels, adjacent playa lake sediments, and in fractured and weathered bedrock. The salinity range of groundwater from the major borefields is given in Table 1.

Table 1. Summary of data from major borefields.

Aquifer	*Borefield*	*Number of bores*	*Production bores (a)*		
			Depth range (m)	*Yield (m^3/day)*	*Salinity (mg/L TDS)*
Alluvium	11-Mile Well	21	40–86	150–400	580–820
	Bellevue	6	26–51	280–610	1500–16200
	Bronzewing	12	35–54	330–670	1000–4080
	Yakabindie	5	35–48	350–900	1380–22500
Calcrete	Darlot	4	30–37	300–500	1290–1600
	Depot Springs	–	26–47	600–4400	710–28800
Eocene sedimentary rocks	Albion Downs	32	56–104	500–1200	2300–160000
	Allans Pool	9	25–84	200–800	1140–1630
	Boo Boo Well				
	Lake Way	–	48–92	320–670	80000–120000
	Mid Gum Pool	10	52–79	400–1200	1040–1590
	Mt McClure	9	67–99	130–490	1160–28800
	South Lake Way	11	63–83	500–900	800–1470
	Yakabindie	–			
Granitoid rock	11-Mile Well	21	40–86	150–400	580–820
Ultramafic rocks and mafic	Caprock	11	58–90	300–1000	880–1960
	Perseverance Fault	2	64–91	400–600	880–1090
	Village	6	55–74	50–260	590–990
	Vivien	1	80	1200	1100

(a) exploratory bore data where no production bores.

Potable groundwater (<1000 mg/L) occurs in elevated areas of enhanced recharge including weathered and fractured bedrock along catchment divides, and in the upper reaches of palaeodrainages, such as Transect J. Alluvium and colluvium, adjacent to bedrock outcrops, contain small supplies of low-salinity groundwater. Calcrete in the Yeelirrie area locally contain large supplies of fresh groundwater where the calcrete receives increased recharge via stream runoff and local flooding.

Brackish groundwater (1000-3000 mg/L) is widely distributed throughout SIR SAMUEL. The tributaries comprising alluvium, colluvium and palaeochannel sand often contain brackish groundwater, such as in Transect I, that progressively increases in salinity downstream towards the main trunk drainages. The low-salinity groundwater in the upper parts of the palaeochannel tributaries is indicative of modern recharge. As calcrete is generally located in the lower reaches of the palaeodrainages, it commonly contains brackish groundwater of 2000 to 6000 mg/L (Sanders, 1969).

Saline groundwater (3000-35 000 mg/L) is associated with the lower reaches of the tributaries, and within alluvium and colluvium in the palaeodrainages. The weathered and fractured bedrock contains variable supplies of saline groundwater, with the higher salinity groundwater occurring in all rock types when low in the landscape.

Hypersaline groundwater (>35 000 mg/L) occurs mainly in palaeochannels and in bedrock adjacent to playa lakes. The high salinities of groundwater in playa lakes result from the concentration of salts as water evaporates from the lake surface. The salts in the hypersaline groundwater of the palaeochannels may have been accumulating for hundreds to thousands of years (Commander *et al.*, 1994).

4.1.2 Variation within aquifers

Groundwater salinity of the alluvial aquifer ranges from 1000 to 4000 mg/L on the flanks of the palaeodrainages and below alluvial fans, with higher salinity water encountered in the lower parts of the drainage system and towards salt lakes. Colluvium deposited on the flanks of greenstone ridges contains low-salinity groundwater, up to 3000 mg/L, owing to surface runoff from outcropping bedrock. Groundwater within the lake sediments is saline to hypersaline, with salinities exceeding 200 000 mg/L.

Groundwater in the calcrete is commonly brackish to saline, between 2000 and 6000 mg/L, because of its position in the lower reaches of drainages. There are small potable supplies at Yeelirrie (Australian Groundwater Consultants, 1981), where the calcrete receives enhanced groundwater recharge via direct rainfall infiltration, and more particularly inundation from surface runoff surrounding catchments during intense rainfall. Groundwater salinity in the calcrete can increase significantly with depth and during periods of high abstraction.

The groundwater salinity in the Tertiary sediments of the palaeochannels generally increases steadily downstream from about 1000 mg/L in the upper parts of the palaeodrainage systems to about 220 000 mg/L near playa lakes (Fig. 3). However, there are local variations to this pattern. Salinity within the palaeochannel sand decreases downstream from 223 000 mg/L near Lake Miranda to 27 000 mg/L at Transect G, indicating significant lateral recharge by low-salinity groundwater from the Gum Pool tributary. There is also apparent stratification of groundwater in the sand aquifer with denser, high-salinity groundwater at the base of the aquifer, such as at Transect K.

Although salinity variation in the granitoids is poorly understood, groundwater salinity in the granitoids will typically be lower in elevated areas. In the 11-Mile Well borefield at Leinster, the salinity in the granite aquifer is fairly uniform, ranging from 520 to 820 mg/L. However, this aquifer receives enhanced recharge via the overlying alluvium (Groundwater Resources Consultants, 1989).

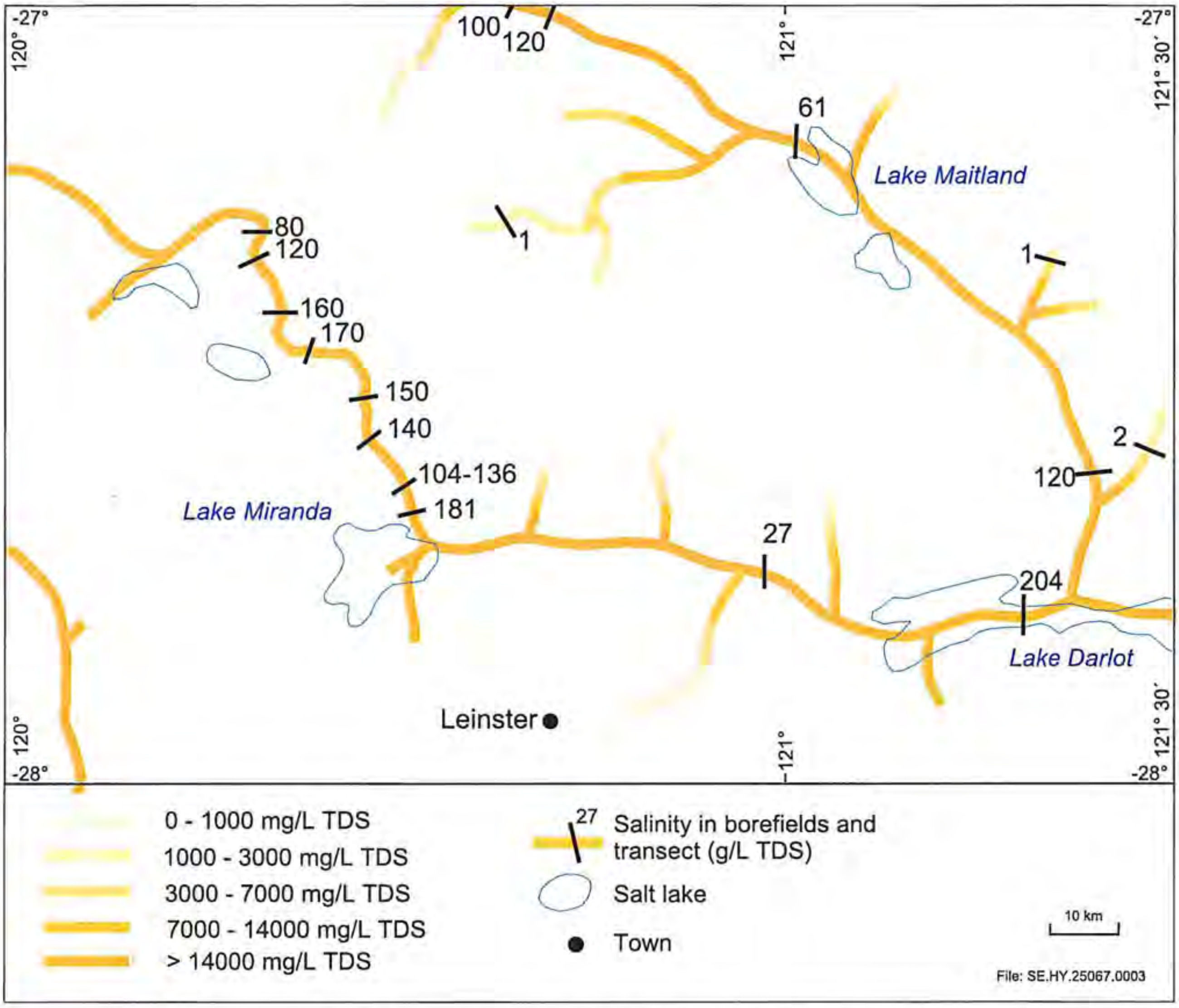

Figure 3. Groundwater salinity in the palaeochannels.

The groundwater salinity in different types of greenstone aquifer tends to be highly variable, ranging from less than 1000 mg/L at the Village borefield to over 50 000 mg/L elsewhere throughout SIR SAMUEL. Local variations in groundwater salinity are common, such as in the Caprock borefield where the salinity ranges from 880 to 1960 mg/L. Mine dewatering of underground operations throughout SIR SAMUEL shows that there is an appreciable increase in groundwater salinity with depth.

4.2 Hydrochemistry

The results of chemical analyses of groundwater from 28 sampling points are presented in Table 2, and the major ions from the chemical analyses are plotted on trilinear diagrams in Figure 4. Most waters are of sodium chloride type irrespective of the aquifer, reflecting their derivation (through precipitation) from cyclic salts. This is confirmed by the composition of the major ions of saline groundwater being close to that of seawater.

Table 2. Selected chemical analyses of groundwater.

Bore/well	*pH*	*EC (a) (mS/m at 25°C)*	*TDS (b)*	*Total hardness*	*Total alkalinity*	*Ca*	*Mg*	*Na*	*K*	*HCO_3*	*Cl*	*SO_4*	*NO_3*	*SiO_2*	*B*	*F*
			(mg/L)													
Alluvium																
PB4 (Bellevue borefield)	8.5	6 100	3 710	-	-	56	84	1 140	43	200	1 800	260	50	-	-	0.8
BJP1 (Bronzewing borefield)	7.4	-	1 800	-	160	84	48	240	21	190	680	190	85	-	-	-
NEF-4c	7.3	208 000	187 700	24 000	88	410	5500	65 000	2700	88	97 000	17 000	47	36	-	-
NEG-1c	8.1	5 800	2 810	430	180	56	70	860	30	180	1 300	230	82	77	-	-
NEH-6c	8.3	3 500	1 830	360	220	45	62	510	44	220	680	180	87	68	1.1	1.0
NEI-1c	8.3	2 900	1 820	600	170	100	62	380	34	170	610	350	85	81	1.1	0.7
NEJ-1c	8.1	1 600	970	310	180	60	39	200	28	180	220	150	79	90	1.0	0.9
Calcrete																
PB1 (Darlot borefield)	7.9	2 000	1 300	-	-	49	43	290	35	245	360	150	90	-	-	0.6
ETP11 (Depot Springs)	7.3	-	4516	817	191	142	124	1 270	73	220	2 007	495	70	-	-	3.4
NEK-1c	8.2	15 000	5 700	1 600	250	160	290	2 600	180	250	3 900	1 200	110	96	-	-
Eocene sedimentary rocks (palaeochannel sand)																
ABD12 (Albion Downs borefield)	7.4	220 000	120 000	-	-	700	3 400	36 000	2 500	120	64 000	14 000	45	28	-	0.8
DP7/7 (Lake Way borefield)	7.4	220 000	120 000	-	-	700	3 400	36 000	2 500	120	64 000	14 000	45	28	-	0.8
LWB029P (Mid Gum Pool borefield)	8.4	4 220	1 600	-	-	70	80	280	23	275	450	170	92	-	-	-
SLW02 (South Lake Way borefield)	7.7	1 400	820	-	-	49	43	170	14	160	260	110	48	84	0.9	-
NEF-4b	7.4	206 000	203 900	23 000	92	96	5600	79 000	2 900	92	98 000	18 000	37	24	-	-
NEG-1b	8.0	44 000	26 900	4 700	220	370	910	9 500	270	220	13 000	2700	23	28	-	-
NEI-1b	8.1	2 100	1 180	460	160	75	66	230	23	160	360	230	62	41	1.0	0.7
NEJ-1b	8.1	1 800	1 010	370	130	70	48	210	17	130	290	180	71	47	1.0	0.7
NEK-1b	7.9	108 000	86 500	15 000	330	400	3 400	27 000	1 400	330	41 000	13 000	73	47	-	-
NEL-6 @ 57m	7.3	163 000	125 510	18 000	75	740	4 000	48 000	1 900	75	61 000	9 700	95	30	-	-
NEL-14 @ 54m	7.3	190 000	167 300	22 000	84	700	4 900	64 000	2 600	84	83 000	12 000	57	21	-	-
Granitoid rocks																
GPB067 (11 Mile borefield)	7.3	1 300	844	-	-	60	60	174	16	100	277	150	61	-	-	-
LWB010P (11 Mile borefield)	7.1	1 100	710	-	-	48	36	130	14	240	285	120	25	-	-	-
Sedimentary, felsic volcanic and volcaniclastic rocks																
VB1 (Village borefield)	7.9	1 370	1 100	-	148	51	64	195	18	180	310	170	78	18	0.7	0.4
Mafic and ultramafic rocks																
PB1 (Bellevue borefield)	8.0	2 070	1 260	-	-	75	41	304	8	85	470	85	55	-	-	0.7
LWB19P (Perseverance borefield)	7.2	1 640	998	-	-	70	40	219	19	88	366	173	51	-	-	-
VB4 (Village borefield)	7.8	1 180	760	-	68	37	24	160	15	82	220	75	75	40	0.6	0.5
VP1 (Vivien borefield)	7.6	1 720	1 100	-	-	15	31	245	21	125	180	140	44	-	-	-

Notes: (a) EC=Electrical conductivity; (b) TDS=Total dissolved solids.

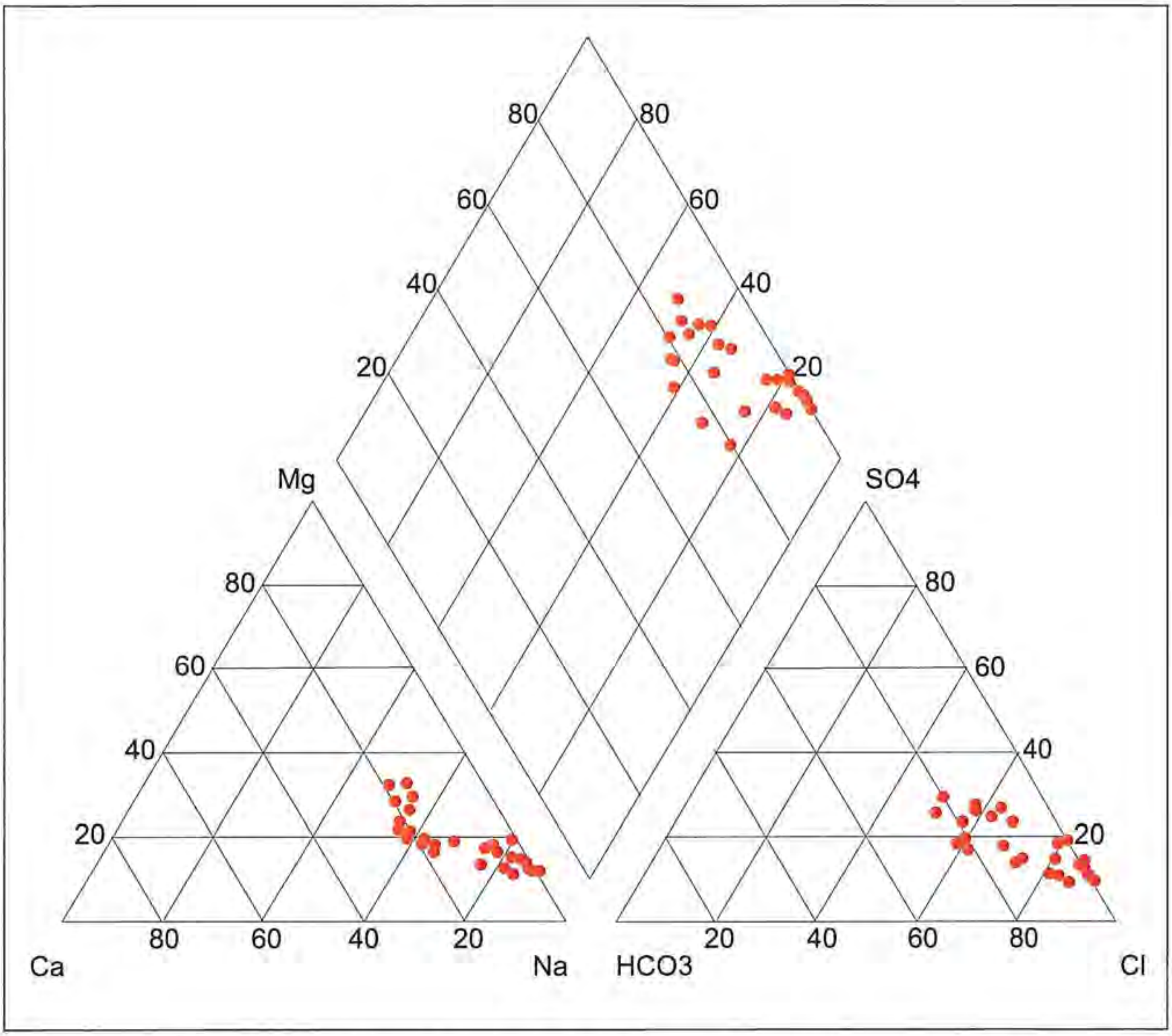

Figure 4. Piper trilinear diagram of selected chemical analyses of groundwaters.

The pH ranges from neutral to slightly alkaline with most groundwater sampled having a pH between 7.1 and 8.5. The preferred alkalinity for carbon-in-pulp and carbon-in-leach circuits for gold ore processing is between pH 9.0 and 9.5. Low groundwater pH, which causes severe metal corrosion, can be raised, usually by adding lime. Conversely, high concentrations of sulphate and magnesium in mine-process water cause scaling problems.

There are relatively high concentrations of nitrate throughout SIR SAMUEL. The analyses listed in Table 2 show that nitrate commonly exceeds the 45 mg/L standard for drinking water, with a maximum concentration of 110 mg/L at Transect K. The likely sources of the nitrates may be related to nitrate-fixing bacteria associated with soil crusts and termite mounds (Jacobson, 1993) and to nitrate-fixing vegetation. Locally, around stock watering points, there may be nitrate contamination from animal faeces.

Bores in the alluvium and calcrete aquifers contain high levels of silica, up to 96 mg/L at Transect K, although these are not considered harmful. Concentrations of boron in the alluvium and calcrete, which exceed the 0.3 mg/L standard for drinking water, are probably related to surface runoff from weathered granitoid catchments. Fluoride is generally very low, although there are elevated levels in the calcrete aquifer at Depot Springs with up to 3.4 mg/L in Bore ETP11 (Geotechnics, 1972).

5 Groundwater development

5.1 Groundwater exploration

Geophysical techniques have been used with varying success to locate palaeochannels on SIR SAMUEL. Seismic and resistivity methods used in the 1970s to determine depth to bedrock and salinity variations in the calcrete aquifers produced satisfactory results. Since the 1980s, gravity and transient electromagnetic methods have proved successful in identifying prospective exploration targets in palaeochannels. Techniques such as airborne electromagnetic methods were used successfully by Western Mining Corporation in locating palaeochannel sediments for the South Lake Way borefield.

The air-core drilling technique is used extensively in the Northern Goldfields to explore and delineate the palaeochannels; however, many of these drill holes have been abandoned due to running sands. Most production bores are installed using mud-rotary drilling, as this method enables the hydrostatic pressure in the palaeochannel sands to be balanced by the column of mud.

Preliminary exploratory drilling to locate useful water supplies in bedrock areas is usually carried out using rotary air-blast (RAB) and reverse circulation (RC) technologies. The bedrock aquifers normally contain localised groundwater supplies within fractures that are difficult to locate, and therefore require a large number of exploratory bores. The hydrogeology is likely to be complex, reflecting the variety of bedrock types, structure, degree of weathering, and wide range of salinities. Bore yields reflect the degree of fracturing and type of weathering (Table 1).

5.2 Mining

A large number of bores on SIR SAMUEL have been drilled by mining companies to obtain water for mineral processing. The borefields are therefore located close to mining centres and obtain groundwater from alluvium, calcrete, palaeochannel sediments or highly weathered and fractured Archaean bedrock.

The alluvium and calcrete aquifers are largely under-utilised by the mining industry. Groundwater allocation from the alluvium is about 3.3 x 10^6 m^3/yr (as at 1997) from the Bronzewing, Bellevue and Yakabindie borefields. The Darlot borefield, which has an annual groundwater allocation of 0.8 x 10^6 m^3, is the only borefield on SIR SAMUEL established in the calcrete aquifer.

In 1997 there were five existing borefields developed in the palaeochannels on SIR SAMUEL with a groundwater allocation of about 20 x 10^6 m^3/yr. The Albion Downs borefield, which supplies process water to WMC's Mount Keith nickel operations, has the largest groundwater allocation at 8.8 x 10^6 m^3/yr and is supplemented by the South Lake Way and Lake Way borefields. The Leinster Nickel operations obtain brackish process water from the Mid Gum Pool and Allans Pool borefields, which are positioned in a palaeotributary (Meyer and Richards, 1990). There has been further exploration in the palaeochannel aquifer downstream of the Albion Downs borefield for the proposed Yakabindie operations. In addition, a number of bores in the Mount McClure borefield are also established in the palaeochannel sand (Mackie Martin and Associates, 1989).

Groundwater allocation from fractured and weathered bedrock was estimated to be about 2.5 x 10^6 m^3 in 1997. The Caprock, Perseverance Fault and Village borefields are the major borefields in highly weathered and fractured bedrock.

The largest groundwater supplies are found in Tertiary palaeochannel aquifers. The groundwater in storage in the palaeochannels is very large when compared with the estimated recharge. Drawdown in these borefields has been lower than predicted from short-term pumping tests, indicating that there is significant inflow from tributaries, weathered and fractured bedrock, and by leakage from the overlying sediments. In most pumping tests, the aquifer responses indicate confined conditions which are likely to remain after several years of pumping.

The trunk and tributaries of the Carey Palaeochannel are almost fully exploited on SIR SAMUEL; however, the section of trunk drainage between Lake Miranda and Lake Darlot is undeveloped. The Way Palaeochannel is exploited only in the north associated with the South Lake Way and Lake Way borefields, although there are numerous tributaries that are undeveloped. Most of the Grey Mare Palaeochannel lies on LEONORA; however, the small section on SIR SAMUEL is exploited by the Murrin Murrin Grey Mare borefield. The Raeside Palaeochannel can be inferred to have similar development potential to that of the Carey and Way Palaeochannels. Most groundwater resources in palaeochannels remain undeveloped, as they are remote from centres of demand or in granitic terranes unprospective for mineral deposits.

Groundwater obtained from mine dewatering is also used for ore processing and mining requirements. Information on actual groundwater abstraction related to mine dewatering is limited on SIR SAMUEL. However, in 1998, some 0.3 GL was abstracted from in-pit sumps and dewatering bores in the Mount Keith open cut. Dewatering will result in major changes to the groundwater regime where pits are being excavated below the watertable. On cessation of mining and dewatering, these pits will eventually fill with water to the level of the regional watertable.

Seepage of highly concentrated saline water may occur from unlined dams associated with the disposal of tailings. Current practice is to line the tailings ponds to minimise leakage, and keep the salts stored within the tailings. Other potential contaminants include cyanide and metal-cyanide complexes.

5.3 Potable

The water supply for Leinster is obtained from the Perseverance Fault and 11-Mile Well borefields, both of which are located in fractured-rock aquifers. The water is also used for mine operations and annual production is about 0.3 GL. Salinity ranges between 600 and 900 mg/L TDS. At present, there are adequate supplies to meet the water requirements of Leinster.

Sufficient supplies of potable to marginal groundwater are available acceptably close to mine sites throughout SIR SAMUEL, with the majority of domestic water supplies on mine sites being abstracted from fractured-rock and calcrete aquifers. In localities where there are poor prospects for locating potable water, small-scale desalination of groundwater can also be used for some domestic supplies.

5.4 Pastoral

The pastoral industry, with about 300 bores and wells, is a major groundwater user on SIR SAMUEL. The distribution of stock-watering points has been dictated more by the foraging range and by paddock system on the pastoral properties than by the availability of groundwater (Allen, 1996). In general, groundwater supplies are easily obtained, but many exploratory sites have been abandoned due to poor drilling conditions, inadequate supplies, or unacceptable salinity (Morgan, 1966).

Most bores and wells used by the pastoral industry are less than 30 m deep, and are typically equipped with windmill-powered pumps that yield up to 20 m^3/day. The alluvium and calcrete deposits are the most extensively utilised aquifers on account of their shallow watertables (<10 m below surface) and low groundwater salinity. Groundwater suitable for stock-watering, up to 5000 mg/L TDS, is readily obtainable throughout the area except in the centres of the palaeodrainages, where water of salinity 8000 mg/L TDS is used occasionally.

5.5 Irrigation

There is local potential for irrigation development throughout SIR SAMUEL. To date, the only development of groundwater for irrigation in the Northern Goldfields has been at Wiluna, north of the sheet area, where in 1969 Desert Farms established citrus orchards irrigated from a calcrete aquifer (Sanders, 1969). It is suggested that for commercial irrigation, aquifers with production bores capable of yielding at least 500 m^3/day are required to ensure peak demand during dry periods. The groundwater salinity requirements are dependent on crop type: citrus requires less than 1000 mg/L TDS, whereas fodder crops such as lucerne and rhodes grass use groundwater up to 3000 mg/L TDS (Johnson *et al.*, 1999).

Calcrete is the most prospective aquifer for horticultural development as the watertable is generally less than 10 m below ground level, bore yields reach 1000 m^3/day, and groundwater is commonly fresh to brackish. The best prospects for low-salinity groundwater for citrus plantations are at Yeelirrie, where the calcrete is recharged via direct rainfall and surface runoff along drainage lines. However, most of the calcrete on SIR SAMUEL contains brackish to saline groundwater that may be suitable only for fodder crops.

The alluvium has limited potential owing to its silty nature, although large supplies of groundwater between 1000 and 3000 mg/L TDS may be available from colluvial deposits adjacent to greenstone outcrops, such as at Transect H. The palaeochannel sand aquifers in the upper reaches of the tributaries, such as at Transects I and J, contain significant supplies of marginal fresh to brackish groundwater. However, the running costs and establishment of deep production bores (up to 120 m) into the palaeochannel sand may be prohibitive to horticultural development.

5.6 Further development

The palaeochannel sand aquifer is considered to be the most prospective aquifer for further development on SIR SAMUEL. It is readily located, exploited and managed, and sustainable yields are much more likely than from weathered and fractured bedrock. The groundwater resources in the Carey Palaeodrainage are sufficient for current and planned mining developments, although the tributaries further downstream on LAVERTON are being increasingly exploited for laterite-nickel ore processing. The Raeside Palaeodrainage appears to have the capacity to supply large quantities of groundwater.

The calcrete aquifer has potential for further development on SIR SAMUEL. There are significant stored groundwater resources in the thick calcrete deposits at Depot Springs (Geotechnics, 1972) and Yeelirrie (Australian Groundwater Consultants, 1981). The remaining calcrete bodies are poorly saturated with the only development potential being for the pastoral industry.

There is only localised potential for further development in the alluvium owing to its silty nature and low permeability. Most groundwater is obtained from the alluvium through leakage into underlying palaeochannel and fractured-rock aquifers during aquifer depressurisation. Colluvial deposits, adjacent to bedrock outcrops, may be suitable for a small-scale groundwater supply.

There appears to be little potential for further large-scale development in the current borefields established within the weathered and fractured bedrock. Low-salinity groundwater can be found in elevated areas of the greenstone belts. The best prospects for locating large supplies of groundwater are in highly weathered profiles developed on ultramafic rocks, and along the contact zones between granitoid and greenstone rocks.

6 Groundwater resources

The groundwater resources of the Northern Goldfields, including those on SIR SAMUEL, are detailed in Johnson et al. (1999). Because the annual recharge from rainfall is very small, groundwater resources on SIR SAMUEL are considered in terms of groundwater held in storage. However, only a proportion of this groundwater is economically recoverable.

The alluvial and colluvial deposits contain by far the largest groundwater resources in the Northern Goldfields. Based on a specific yield of 0.05 and a saturated thickness of 10 m, the groundwater storage in the alluvium on SIR SAMUEL is estimated at 3100 x 10^6 m^3 (Johnson et al., 1999). On a regional scale, groundwater resources in the alluvium probably represent more than 70% of the total groundwater resources on SIR SAMUEL.

Various authors have estimated groundwater resources in the calcrete aquifer throughout SIR SAMUEL. Geotechnics (1972) estimated stored groundwater resources at Depot Springs at 78 x 10^6 m^3, while Australian Groundwater Consultants (1981) indicated that a groundwater resource of 47 x 10^6 m^3 was held within the calcrete aquifers at Yeelirrie. In areas with no information, groundwater storage was estimated using a specific yield of 0.1 and a saturated thickness of 5 m, which suggests total groundwater in storage of 328 x 10^6 m^3 within the calcrete on SIR SAMUEL. Groundwater in the calcrete probably represents about 8% of total groundwater resources for the sheet.

The palaeochannels on SIR SAMUEL contain significant groundwater resources held in storage. Based on a specific yield of 0.2, storage in the palaeochannels on SIR SAMUEL is estimated at about 750 x 10^6 m^3 for 662 km of palaeochannel length (Johnson *et al.*, 1999). The groundwater storage of 1.1 x 10^6 m^3 per kilometre of palaeochannel is comparable with estimates by Commander *et al.* (1992) for the Roe Palaeodrainage. The estimated volume of groundwater in storage is conservative because it does not include groundwater made available by pumping-induced inflow from the surrounding weathered and fractured bedrock, or by leakage from the overlying alluvium and calcrete. Hence, groundwater in the palaeochannels probably represents about 17% of the total groundwater resources on SIR SAMUEL.

The potential resources in weathered and fractured bedrock are difficult to estimate reliably on a regional scale because of their localised and discontinuous nature. Hence, Johnson *et al.* (1999) estimated stored groundwater resources within regional fracture systems using a number of assumptions for specific yield and aquifer dimensions. From this they calculated the total groundwater storage in the weathered and fractured bedrock on SIR SAMUEL to be about 180 x 10^6 m^3. It is likely that the groundwater in the bedrock represents more than 4% of the total groundwater resources of the area.

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Appendix 1

SIR SAMUEL 1:250 000 hydrogeological series digital data reference files and documentation

Design file	Level	Description	Scale of capture (where applicable)
Sstopo.*dgn*	L1	Roads, highway	
	L2	Tracks	
	L5	Cross section transects	
	L6	Airport, landing grounds	
	L11	Dams, tanks	
	L17	Pools, waterholes, rock holes, gnamma holes	
	L20	Intermittent lakes (simplified) and names	
	L21	Creeks, rivers and names	
	L22	Permanent lakes	
	L30	Mine names	
	L31	Mining symbols	
	L32	Mining centre names	
	L41	Localities	
	L42	Road and highway names	
	L43	Mountains, hills, ranges, trig points, rock names	
	L44	Control points; major and minor	
	L45	AMG grid	
	L60	Neatline, latitude and longitude lines	
	L62*	Documentation	
	L63*	Alignment for text around map edge	
Sshydro.*dgn*	L1*	Geological boundaries	1:500 000
	L2*	Outcrop boundary	1:500 000
	L3	Hydrogeological linework	
	L4	Hydrogeological labels	
	L5	Faults	1:500 000
	L6	Linework and labels for outcrop	
	L7*	End of palaeochannels	
	L11*	Palaeochannels	
	L16*	Remaining linear geology	1:500 000
	L17	Chert and banded iron-formation	1:500 000
	L18	Dolerite dykes	1:500 000
	L45	AMG grid – map and side panels	
	L60	Legend, latitude and longitude text	
	L62	Documentation	
Sssal.*dgn*	L1	Salinity linework	1:250 000
	L2*	Salinity labels	
	L10	<1000 mg/L colour fill	
	L11	1000–3000 mg/L colour fill	
	L12	3000–7000 mg/L colour fill	

SIR SAMUEL 1:250 000 hydrogeological series digital data reference files and documentation (cont...)

Design file	Level	Description	Scale of capture (where applicable)
	L13	7000–14 000 mg/L colour fill	
	L14	>14 000 mg/L colour fill	
	L20	Salt lakes	
	L45	AMG grid	
	L60	Scale bar	
	L62*	Documentation	
Sswc.*dgn*	L45	AMG grid	
	L50	Catchment divide	
	L53	Direction of groundwater flow	
	L54	Isopotential lines	
	L55	Isopotential labels	
Ssbores.*dgn*	L1*	Wells from Geonoma	
	L2*	Bores from Geonoma	
	L3*	AQWABase wells	
	L4*	AQWABase bores	
	L5*	Exploration bores — no borefield	
	L6*	Exploration bores — borefield	
	L7*	Old exploration bores — replaced	
	L8*	Monitoring bores	
	L9*	Old production bores — replaced	
	L10*	Production bores >50 m^3/day	
	L11*	Abandoned production bores>50 m^3/day	
	L12*	Production bores — potable	
	L13*	WRC bores	
	L14*	Unknown data point source	
	L15*	Position uncertain	
	L16*	Mine shaft	
	L17*	Main Roads bores	
	L18*	Dewatering bores	
	L19*	Wells – not stored in Geonoma	
	L20*	Bores – not stored in Geonoma	
	L25	Bore names	
	L30	Wells (data from L1)	
	L31	Bores <50 m^3/day (data from L2,5,6,7,17)	
	L32	Production bores >50 m^3/day (data from L10, 12)	
	L33	Abandoned production bores (data from L9, 11)	
	L35	WRC and mining company transects	
	L36	Water pipelines	
	L37	Borefield names	
	L45*	AMG grid	
	L62*	Documentation	

*Note: information not shown on printed map.

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SIR SAMUEL SG51-13
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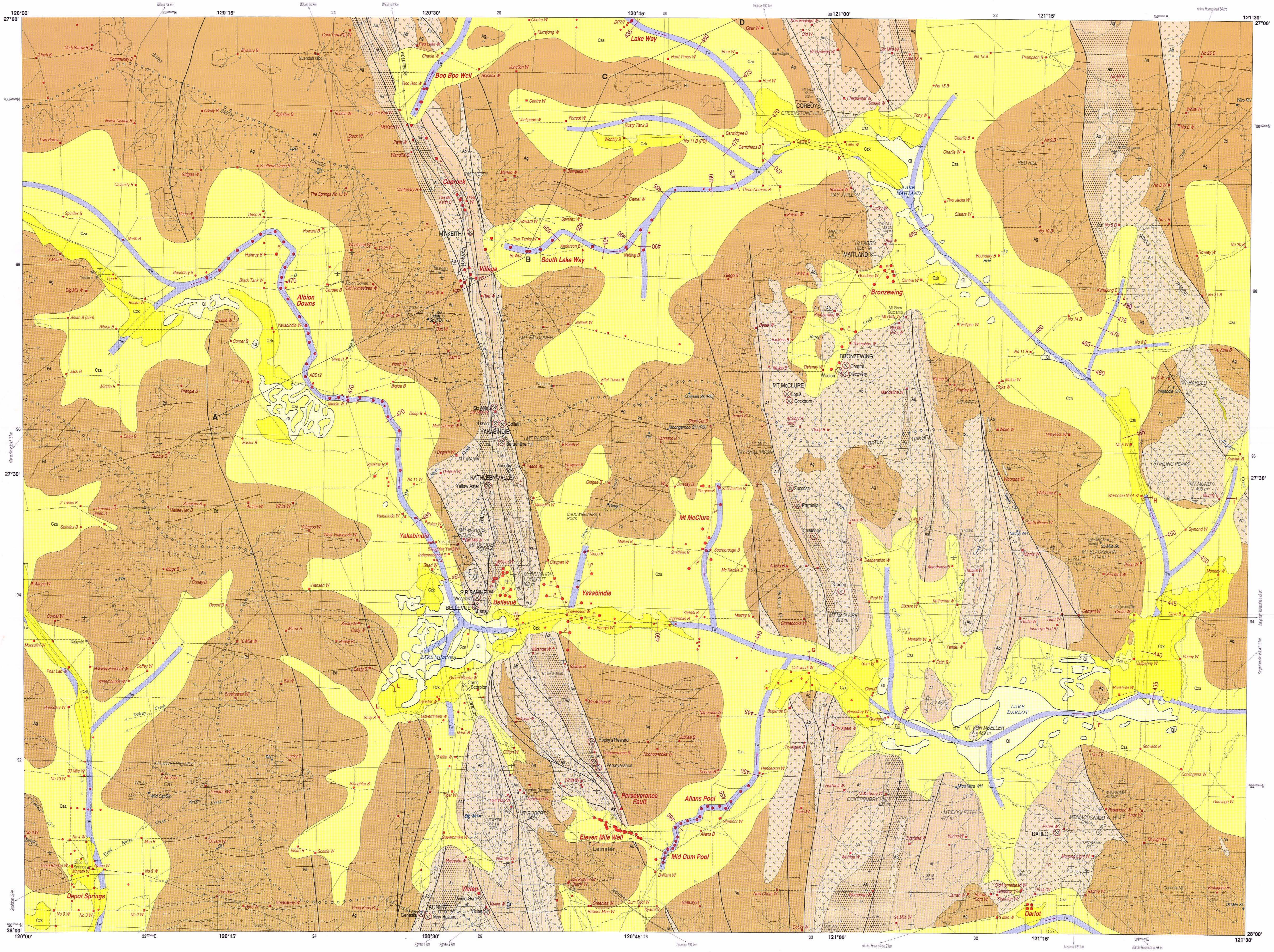
1 : 250 000 HYDROGEOLOGICAL SERIES

SIR SAMUEL

WATER AND RIVERS COMMISSION

SHEET SG 51-13



REFERENCE

AQUIFER TYPES

Surficial deposits — local aquifers, minor to major groundwater resources

Sedimentary aquifer in palaeochannels — major aquifer, major groundwater resources

Sedimentary aquitard in palaeochannels — no groundwater resources (section only)

Fractured and deeply weathered rocks — local aquifers, minor groundwater resources, locally large supplies from fracture zones and permeable horizons in weathering profile

HYDROGEOLOGY

PHANEROZOIC / CAINOZOIC	QUATERNARY	Ql	Playa lake sediments — mostly clay	Minor shallow aquifer, possible small supplies in sands; hypersaline
		Cza	Alluvium and colluvium — clay, silt and sand, minor gravel; conceals palaeochannels	Major shallow aquifer; fresh to hypersaline
		Czk	Calcrete — often with extensive karst development	Significant local aquifer; fresh to saline
	EARLY TERTIARY	Tp	Clay — minor sands; restricted to palaeochannels (section only); equivalent to PERKOLILLI SHALE	Aquitard
		Tw	Sand — restricted to palaeochannels; concealed by palaeochannel clay; equivalent to WOLLUBAR SANDSTONE	Major aquifer; fresh to hypersaline
PROTEROZOIC		Pd	Mafic and ultramafic dykes: interpreted	Very minor local aquifer; brackish to saline
ARCHAEAN		Ag	Granitoid rock; outcrop (indicated by overprint); generally weathered to sandy clay	Local aquifer; fresh to saline
		Ac	Chert and banded iron-formation	Major local aquifer; fresh to saline
		As	Metasedimentary rocks	Minor local aquifer; brackish to saline
		Af	Felsic volcanic and volcaniclastic rocks	Minor local aquifer; brackish to saline
		Ab	Mafic rocks	Minor local aquifer; fresh to saline
		Au	Ultramafic rocks and weathered equivalents	Major local aquifer; fresh to saline

YILGARN CRATON

SYMBOLS

GEOLOGY

hydrogeological boundary
inferred hydrogeological boundary
extent of weathering (section only)
fault or shear zone

SURFACE WATER FEATURES

intermittent drainage
surface water divide
playa lake
RH GH WH rockhole, gnamma hole, waterhole
Sp Sk spring, soak
D dam
T tank

GROUNDWATER FEATURES

470 isopotential (m AHD)
direction of groundwater flow
watertable (section only)

ARTIFICIAL FEATURES

ADB12 production bore; yield >50 m³/day
abandoned bore; yield >50 m³/day
bore
well
Lake Way borefield name, cluster of bores
G WRC exploratory drilling line
P groundwater pipeline
mine dewatering

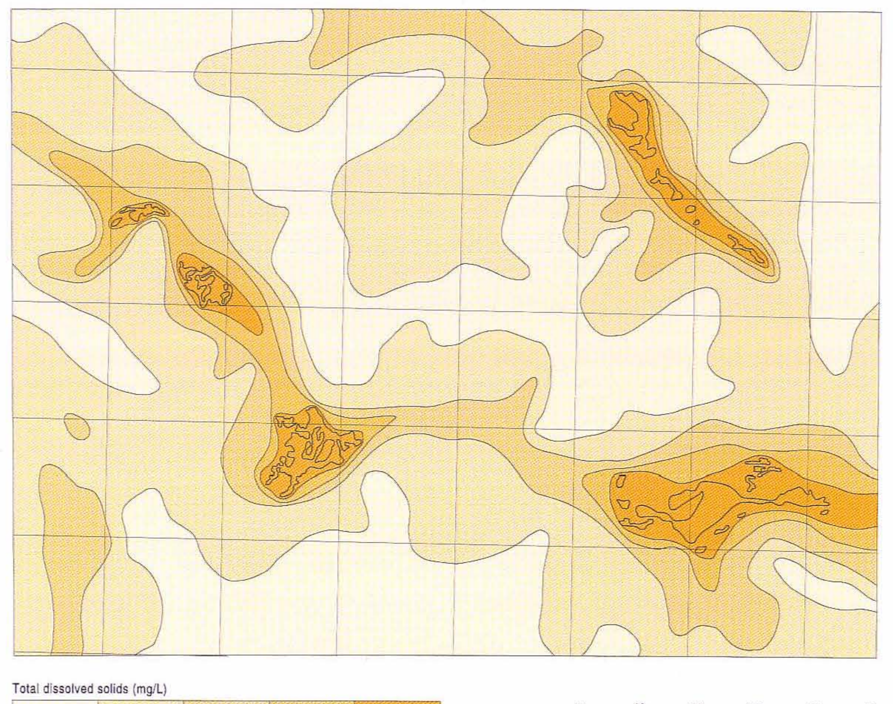
MINING INFORMATION

underground mine, opencut
BRONZEWING mining locality
Central mine name

TOPOCADASTRAL INFORMATION

highway
formed road
track
airfield, landing ground
Leinster townsite, population less than 10 000
Leinster Downs homestead
SS 53 horizontal control; major, minor

GROUNDWATER SALINITY AT THE WATERTABLE



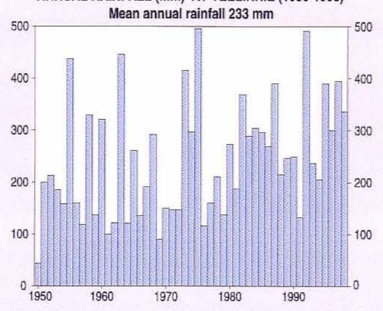
Total dissolved solids (mg/L)
0 1000 3000 7000 14000

0 10 20 30 40 50
Kilometres

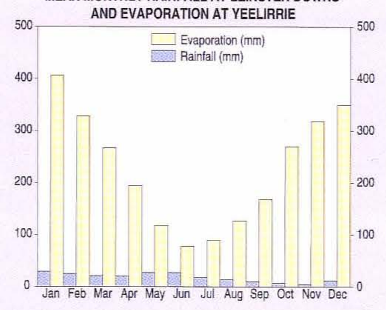
INDEX TO ADJOINING SHEETS

GLENGARRY SG 50-12	WILUNA SG 51-9	KINGSTON SG 51-10
SANDSTONE SG 50-16	SIR SAMUEL SG 51-13	DUKETON SG 51-14
YOUANMI SH 50-4	LEONORA SH 51-1	LAVERTON SH 51-2

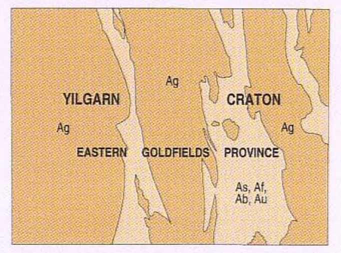
ANNUAL RAINFALL (mm) AT YEELIRRIE (1950-1998)
Mean annual rainfall 233 mm



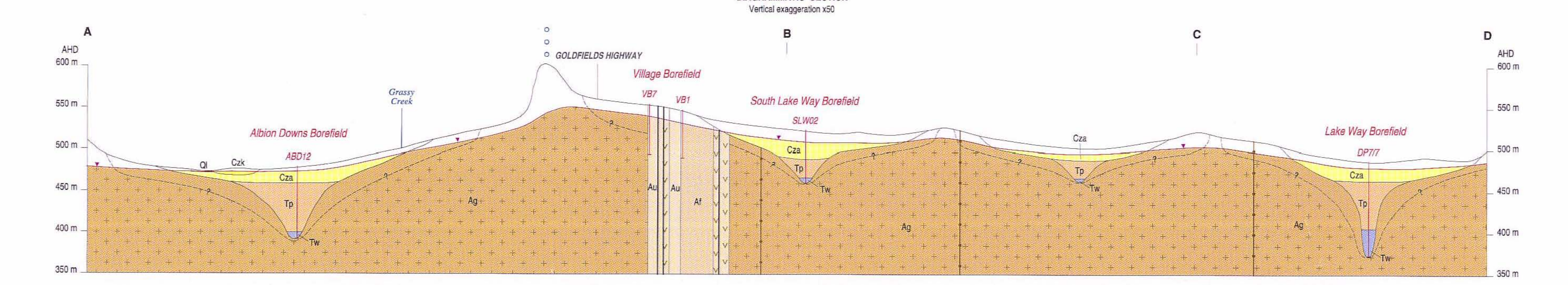
MEAN MONTHLY RAINFALL AT LEINSTER DOWNS AND EVAPORATION AT YEELIRRIE



REGIONAL GEOLOGICAL SKETCH



DIAGRAMMATIC SECTION
Vertical exaggeration x50



Hydrogeology by S.L. Johnson, 1999

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GOVERNMENT OF WESTERN AUSTRALIA
Dr KIM HAMES
MINISTER FOR WATER RESOURCES

WATER AND RIVERS COMMISSION
R. PAYNE
CHIEF EXECUTIVE OFFICER

SCALE 1: 250 000

5000 Metres 0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION

Grid lines indicate 20 000 metre interval of the Australian Map Grid Zone 51

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